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On the Fundamental Periods of Vibration of Flat-Bottom Ground-Supported Circular Silos containing Gran-like Material

"Luca Pieraccini, Michele Palermo, Silvestri Stefano, Tomaso Trombetti" *

*"*Department DICAM, University of Bologna"*

Abstract

Despite the significant amount of research effort devoted to understanding the structural behavior of grain-silos, each year a large number of silos still fails due to bad design, poor construction, with a frequency much larger than other civil structures. In particular, silos frequently fails during large earthquakes, as occurred during the 1999 Chi-Chi, Taiwan earthquake when almost all the silos located in Taichung Port, 70 km far from the epicenter, collapsed. The EQE report stated that "*the seismic design of practice that is used for the design and construction of such facilities clearly requires a major revision*". The fact indicates that actual design procedures have limits and therefore significant advancements in the knowledge of the structural behavior of silo structures are still necessary. The present work presents an analytical formulation for the assessment of the natural periods of grain silos. The predictions of the novel formulation are compared with experimental findings.

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Keywords: flat-bottom on-ground circular grain-silo, seismic response, fundamental period, code-like formula

1. Introduction

The structural design of grain-silos requires accounting for the effect of the ensiled grain on the wall both under static and under dynamic conditions. Grain-silos are considered different to many other civil structures [1] and are usually classified as "non-building structures" [2, 3].

* Corresponding author. Tel.:+39 051 209 3232; fax: + 39 051 209 3236.
E-mail address: luca.pieraccini5@unibo.it

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As widely known, the identification of the natural periods is the basic step for any seismic design. Unfortunately, for flat-bottom grain-silos no reliable formulas are available for the evaluation of the natural periods to date.

Experimental tests show that grain-silos present a marked non-linear dynamic behavior. Therefore, the common methods adopted for the dynamic analysis of common civil structures cannot be straightly applied to grain-silos.

The present study aims at providing an analytical formulation for the estimation of the fundamental period of vibration of flat-bottom circular grain-silos referable to the class of silo with isotropic continuous wall (such as rolled steel plate silos). Starting from the analytical framework proposed by [4] and [5] and adopting the same idealized model, the dynamic behavior of grain-silos is re-conducted to that of an equivalent linear-elastic system.

In the first part of the present paper, a brief review of the experimental and theoretical research works conducted by many Authors related to the dynamic behavior of grain-silos is briefly presented. In the second part of the paper, the theoretical framework adopted, the assumptions, the closed-form expressions for the analytical evaluation of the fundamental period of vibration are presented. Finally, the theoretical estimation is compared with the experimental data gathered via shaking-table tests on a silo specimen containing Ballottini-glass and data available from the scientific literature.

Nomenclature

$t_{w,i}$	Constant thickness of the *i*-th wall portion
Δz_i	Length of the *i*-th wall portion
r	Total number of the wall portions
H_{beam}	Vertical length between the silo bottom and the highest solid-wall contact
d_c	Diameter of the silo
R	Radius of the silo
$\bar{t}$	Uniform equivalent thickness of the equivalent beam
z	Vertical distance between the generic grain layer and the grain free-surface
$m_b(z)$	Mass per unit length corresponding to the *effective mass* of the grain (or bulk solid)
$p_{wf}(z)$	Wall frictional traction at a distance *z* under static condition
μ_{GW}	Grain-wall friction coefficient
γ_b	Unit weight of the ensiled bulk material
γ_w	Unit weight of the wall material
g	Gravity acceleration
λ	Pressure ratio
$p_0(z)$	Horizontal pressure according to Janssen's formulation
$m_w(z)$	Mass per unit length of the silo wall
$t_w(z)$	Thickness of the silo wall
$\overline{m}$	Uniform mass per unit length of the equivalent beam
$\overline{t}_w$	The uniform thickness of the equivalent beam leading to the same wall mass of the silo
m_{eff}	*Effective mass*
Δ	Slenderness ratio
χ	Shear coefficient
$f_{n,sh+flex}$	Fundamental frequency accounting for both shear and flexural deformations